4 Programmable Logic Controllers

SUJATA AGASHE AND SUDHIR D. AGASHE

PARTIAL LIST OF SUPPLIERS

Allen Bradley (http://www.ab.com/)
B&R Automation (www.br-automation.com)
GE (http://www.ge.com/)
Messung (www.messung.com)
Mitsubishi (http://www.mitsubishicorp.com/jp/)
Omron PLC (http://omron-plc.com/)
PLC Hardware (http://www.plchardware.com/)
Siemens (http://www.usa.siemens.com)
Schneider Electric (http://www.schneider-electric.com/corporate)
Toshiba (http://www.toshiba.com/)

INTRODUCTION

Automation is a key word for industries where plants are running with optimum utilization of resources to achieve high efficiency and increased productivity. The degree of sophistication of real-time automatic system is based on how the signals/images are processed. These techniques change day by day due to technological advancements. Research in process control and automation has gained momentum in last three decades. This change is due to the rapid advances in computational technology, networking, control system, and process optimization. The competition due to globalization resulted in better process control, optimum utilization of resources, and higher level of automation in all process industry sectors. New control paradigms are developed, with ease of operation, less downtime, prediction, and correction for performance degradation of control components. One technique being promisingly used by industry is the programmable logic controllers (PLCs). The PLC is a tool mainly used to control plants where discrete signals dominate the continuous signals. In this chapter, the step-by-step procedures to develop and test logic are discussed. The related information on the hardware is also described for easy selection and implementation.

TYPES OF PROCESSES

The process knowledge is essential to implement the automation philosophy. Process is a method or procedure developed to achieve predefined results. Prior to the development of these techniques, knowledge on types of process, process complexity, and extent of automation required is essential. Mainly, processes can be divided into three categories:

- Continuous process
- Batch process
- Composite process

Continuous process: In this type of process, the operation is continuous except for failures and routine maintenance schedules. The raw material enters the process at a predefined rate and proceeds through a number of stages until the final product is ready. In summary, the feed is continuous and output is also continuous.

Batch process: In this type of process, raw material is fed once. Subsequently, various operations are carried out to convert the raw material into final product. The feed is charged again only after the delivery of the product of first cycle.

Composite process: This is a combination of continuous and batch process. In this case, the part of the process material entry is continuous whereas the remaining part of the process is a typical batch process.

The decision for selection of automation tool such as stand-alone controllers, PLC, and digital control systems (DCS) depends on the nature of the process and complexities involved. Hence, it is advisable to study the process and its implications on developing automation strategies.

EVOLUTION OF AUTOMATION

Prior to the advancements in electronics and computational technologies, the relay-based logic dominated the world of automation. In the automobile industry, these techniques were used to control the sequential operations of the plant. The development cycle of the current PLC technique can be listed as:

- Electromechanical (relay) control
- Hardwired electronic control
- Programmable logic control

Electromechanical (relay) control: An electromechanical relay/contactor is used to switch the operation based on a

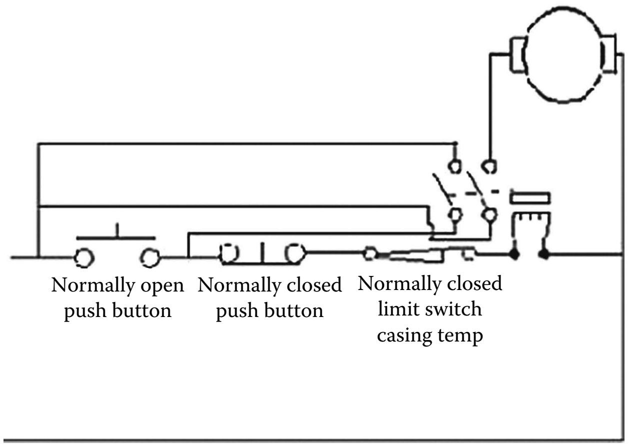
Normally open push button
Normally closed push button
Normally closed limit switch casing temp

FIG. 4.1
Electrical wiring for motor ON-OFF with casing temperature interlock.

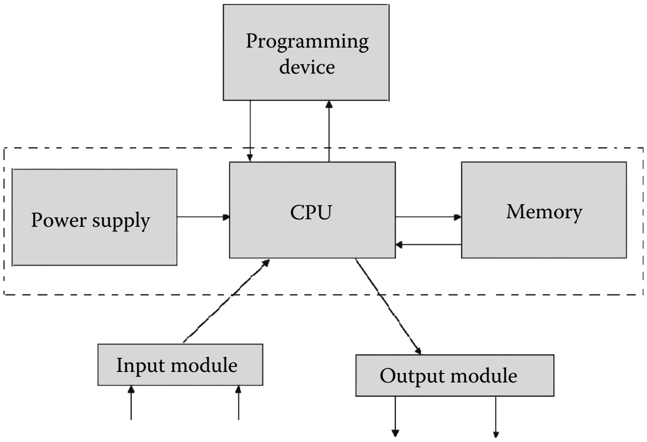

FIG. 4.2
PLC block diagram.

sequence of events. Figure 4.1 shows the operation of switching "ON" a motor if the operator presses start push button and switches "OFF" if stop push button is pressed. If the casing temperature goes high, the motor will be tripped and needs to be started again by the operator. This will ensure the safety of the machine.

Advantages: Easy operation, wiring, and trouble shooting.

Limitations: Difficult for online changes, generation of noise, and limited life of relay.

Hardwired electronic control: In this type, the solid-state devices like thyristors, ICs, and displays are used. Additional features like sequence monitoring indication, faults, and self-diagnosis are possible while designing the system.

Advantages: Extended life due to solid-state devices, reliablity, and compactness in size.

Limitations: System expert required for implementing changes, costly.

Programmable logic controllers: A promising technology with ease of operations and development of logic for automation of plants. The system supports various types of inputs and outputs. The logic developed is stored in software forms and very easy to change online. The input and output side connections are fixed and need not be changed as per the logic.

Advantages: Compact, reliable, flexible, and easy maintenance.

Limitations: Expert manpower required for handling, costly.

PROGRAMMABLE LOGIC CONTROLLERS

PLC is defined as a digital electronic device that uses programmable memory to store instructions and to implement specific functions such as logic, sequence, timing, counting, and arithmetic to control various machines and processes.

The PLC consists of:

- Input modules
- Output modules
- Central processing unit (CPU)
- Memory
- Power supply
- Programming devices

The block schematic of the PLC is as shown in Figure 4.2.

INPUT MODULES

This is an interface between the field devices and CPU. This module converts the input signal into logical signal with which the CPU works. The block schematic of the typical input module is as shown in Figure 4.3.

Main functions of input modules are:

- Indicating the status of input conditions
- Providing electrical isolations
- Contact debouncing
- Noise elimination
- Signal conditioning for compatibility

There are various types of input modules. Based on the direction of electrical current, these modules are classified as sinking types as shown in Figure 4.4 and sourcing types as shown in Figure 4.5.

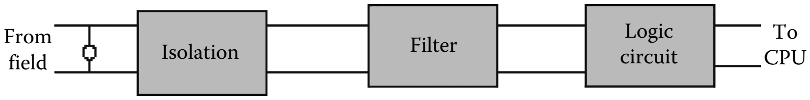

FIG. 4.3
Input module block diagram.

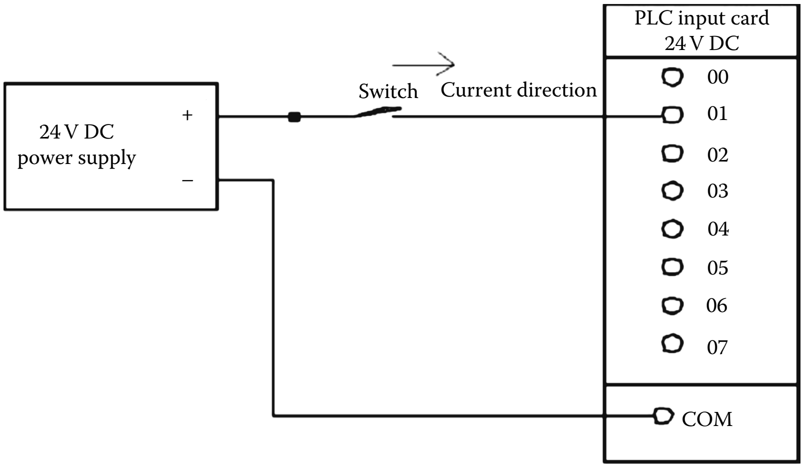

FIG. 4.4
Sinking type input module.

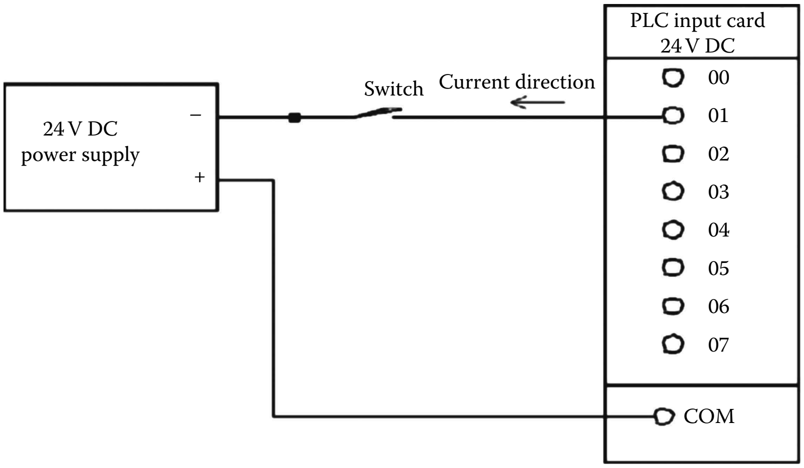

FIG. 4.5
Sourcing type input module.

Based on the types of inputs, these modules are classified as:

Discrete input modules: This module accepts input from discrete devices such as limit switches, push buttons, proximity switches, and selector switches, etc. This module sends the signal based on the state of the device as logic 1 or 0. This signal can be either AC or DC. The typical wiring diagram of the digital input module is as shown in Figure 4.6.

Analog input modules: The module accepts analog signal in the form of continuously varying current or voltage. The standard types of inputs are 4–20 mA, 1–5 V, Thermocouple, RTD, etc.

Typical Specifications of the Input Modules are:

- *Operating voltage*: This is the voltage level required by the module for its operation.
- *Number of inputs*: This indicates the number of inputs that can be connected to the module. Typical numbers are 8, 16, and 32.
- *Points per common*: This is the group of input terminals that shares the common point. In case of input module shown in Figure 3.6, eight inputs are sharing one common terminal. Hence, it is eight points per common.
- *Backplane power*: This is the power required for the module to work and this is fetched from the power supply of the PLC. Depending on the number of cards connected to rack, the back plane power supply will vary.
- *Max signal delay*: It is the time required for the module to detect the state change of the input.
- *Max off-state current*: It is the leakage current the module carries when the input device is in off state.

OUTPUT MODULES

This module interfaces the actions generated by the CPU to the output devices. The block schematic of the output module is shown in Figure 4.7.

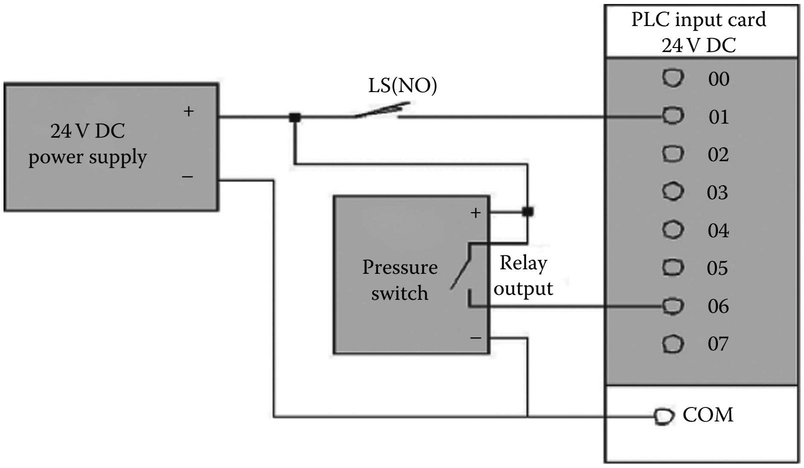

FIG. 4.6
Typical wiring diagram for digital input module.

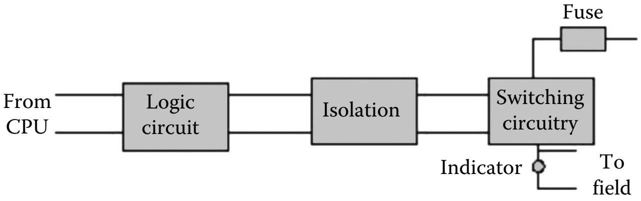

FIG. 4.7
Output module block diagram.

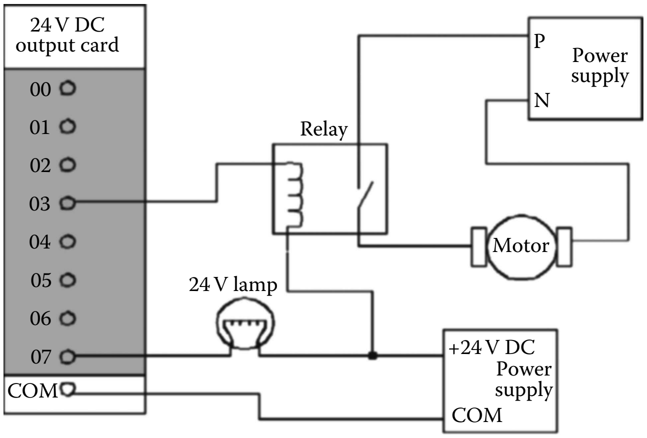

FIG. 4.8
Typical wiring diagram for digital output module.

Main functions of the module are:

- Signal conditioning for compatibility with output devices
- Status indicator
- Electrical isolation

Types of Output Modules are:

Discrete output modules: This module transmits actions of the CPU to the devices like relays, pilot lamps, solenoids, contactors, etc. Options like relays, Transistor-to-Transistor Logic (TTLs), or isolated outputs are available for the selection of output module. The typical wiring diagram for the output module is as shown in Figure 4.8. These cards consume power from backplane power supply.

Analog output modules: The CPU generates the digital signal, which in turn gets converted to analog signal using digital to analog converter (DAC or D/A), which is an integral part of this module. This type of module outputs signals in the form of 4–20 mA, 1–5 V.

The specifications of the module are similar to that of input card. The high density card option is available for input/output (I/O) modules. In these cards typically, 32 input or outputs can be connected to the CPU. This reduces the space required for the housing of the card in the chassis.

CENTRAL PROCESSING UNIT

This is the heart of the PLC. It controls the operation of the PLC. It is responsible for solving the logic as well as performing timing, counting, arithmetic, PID, and other advanced functions. The CPU sequentially carries out the operation called "scanning." The scan consists of series of sequential operations, which include data input, program execution, data output, housekeeping, updating the programming devices, communication with other devices, and diagnostics. Once the CPU is configured and put in RUN mode, it continues to repeat these operations. The CPU performs its operation in three modes viz. Program, RUN, and Remote Run.

In case of program mode, a user can enter/modify the program. The program needs to be downloaded in the CPU.

The processor executes the program in the RUN mode.

The status of the CPU can be seen from the indicators located on the front facia of CPU. The indicators are RUN, FAULT, I/O, MEM, and BAT. Under normal working of the

PLC, the MEM, FAULT, I/O, and BAT indication remains off. If the PLC is in run mode, RUN is on.

Input scan: In this cycle, the CPU scans the status of all the inputs and stores it in the memory as input status table.

Program scan: The CPU solves the logic a user has stored in the memory in this mode. The results of the logic solve are sent to the output status file.

Output scan: The results received at the program scan are updated and physically the status of the output is changed in this scan.

Scan time is defined as the time required for the CPU to complete one cycle of operation viz input scan, program scan, and output scan. Typically, the scan time is 7 ms/K of memory. Hence, the scan time depends on the size of the program, number of I/Os, and the processor used.

House keeping: The operations like memory management, updating processor status file, and other internal registers are carried out in this scan cycle.

Specifications of CPU

The selection of CPU mainly depends on the requirements of the user. Each CPU supports certain operations and memory size. Normally, depending on the number of I/Os and complexities involved for the plant automation, the required CPU can be identified. The major specifications are:

- Program memory
- Local I/O capacity
- Remote I/O if any
- Total number of slots including future expansion
- Typical scan time
- Instructions
- Memory backup
- RAM backup
- Programming methods

MEMORY

There are two types of memory system and user memory. In system memory, the data files are stored whereas user memory is used for storage of program files. The data files comprise input, output, status, bit, timer, counter, register, and integer files. The physical location of the I/O in the rack of the PLC is mapped to the memory location. This technique is called as addressing. The address requires information like rack, group, and slot. For example, if a 16 digital input card is placed in the third slot of the first full rack (16 slots) of the PLC and the level switch is connected to the fifth position of the card, then the input address will be I: 003/05. If the similar card is placed in the 10th slot, then the address will be changed to I: 013/05. This information will be saved in the input file of the data memory. The status file stores the information about the major and minor faults occurred during operation of the PLC. This information is very useful at the time of trouble shooting. The user programs are stored in various files of user memory. These can be modified by the user as per the requirement.

POWER SUPPLY

In PLC, two types of power supplies are used. The power supply used for powering the cards and installed in the rack is called as back plane power supply. This power supply is generally specified by the manufacturer depending on the racks and cards ordered by the customer. The power supply is not used for driving the load in the field.

The loads like transmitter, solenoid coils, pilot lamps, etc. are driven by bulk power supply. This is external to the PLC system. Depending on the number of loads to be driven and consumption of each load, the rating of the power supply is calculated. Generally, this power supply is customer's requirement and needs to be ordered separately.

PROGRAMMING DEVICES

For modification and or loading of new program, a programming device is used. Various programming devices are available like hand-held communicator (HHC), PC, and memory chip. The selection of these programming devices depends on the stage of the project. In case of a new development, a PC is preferred whereas for the minor modifications at site, HHC is recommended and if the program is tested and no changes are expected, then memory chip is used.

PLC PROGRAMMING

Based on the requirements of the vendors, users, and experts working in the field of PLC, a standard was developed to apply uniform structures for programming. IEC 61131 Part 3 refers to the standard for programming. The PLC program can be developed using various programming methods such as

1. *Ladder diagram*: Ladder diagram is a widely used and mostly accepted way of PLC programming. In this technique, the program is expressed in the form of a ladder. It consists of two vertical lines. The left line represents positive or active power supply and the right line represents negative or neutral supply. Between the supply rails, lines called rungs made of various I/O devices are included. The ladder diagram represented is always in de-energized form. The sample ladder is as shown in Figure 4.9. In the ladder, the left side of the rung where the input devices are connected is known as "condition area." The right most side of the

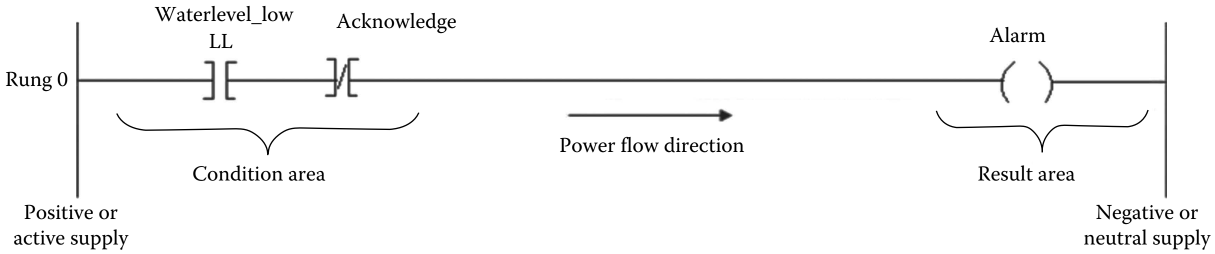

FIG. 4.9
Typical ladder diagram.

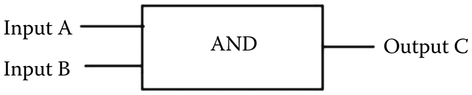

FIG. 4.10
Example of FBD diagram.

rung is "result area" where output device is connected. Based on the conditions of the input devices located in the condition area, the output device is activated.

2. *Function block diagram*: The function block diagram (FBD) is a technique in which the instructions are clubbed in one or more blocks. These blocks can be combined for the purpose of development of logic. The example of FBD is as shown in Figure 4.10.
3. *Sequential function chart*: In some plants simultaneous operations are expected to be performed by the PLC. This concurrent processing is achieved with a graphical technique known as sequential function charts (SFC). The sample SFC is represented as shown in Figure 4.11.
4. *Instruction list*: This programming method is similar to assembly language programming used in microcontrollers. Typical example is as shown in Figure 4.12. This programming method is rarely used.

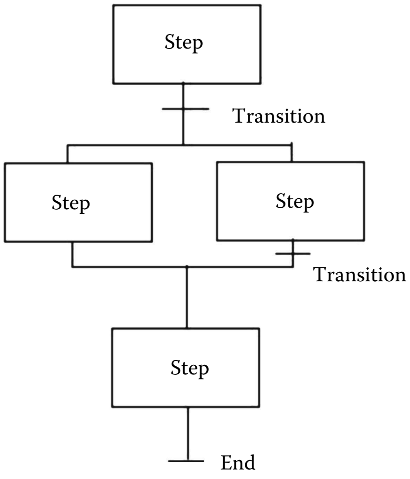

FIG. 4.11
Sequential function chart example.

```
LD A
AND B
ORC
ST Y1
LD A
AND NOT B
ST Y2
```

FIG. 4.12
Instruction list program.

```
PROGRAM main
VAR
        I: INT;
END_VAR
I: = 0;
REPEAT
        I: = i + 1;
        UNTIL i> =5;
END_REPEAT;
END_PROGRAM
```

FIG. 4.13
Structured text example.

5. *Structured text*: Similar to C language, this programming technique is developed. The program is called *main* and is written between statements *PROGRAM* and *END_PROGRAM* as shown in Figure 4.13.

INSTRUCTIONS USED IN LADDER PROGRAMMING

Common instructions used in ladder programming are Examine ON, Examine OFF, Coil, Latch, and Unlatch. These are referred as bit or relay instructions. The symbolic representation of the same is as shown in Table 4.1.

Other than bit instructions, software timers and counters are available in PLC for timing or counting applications.

Timers

In PLC, three types of timers are generally used, viz. on delay (TON), off delay (TOFF), and retentive timer (RTO). The configurable parameters for the timers are time base,

TABLE 4.1
Bit Instructions

Instruction	*Symbol*	*Description*
Examine ON (normally open)	—| |—	An input condition that is open when de-energized
Examine OFF (normally closed)	—(/)—	An input condition that is close when de-energized
Output coil	—( )—	An output instruction that is true when the input conditions become true
Negated output		An output instruction that is true all the time except when all input conditions are true
Latch output coil	—(L)—	To hold an output ON
Unlatch	—(U)—	To unlatch the latched ON output
One-shot	—(OSR)—	To make the output ON for pulsed input

preset, and type of timer. The output bits available for the timer are enable, done, and timer timing. A developer can use any of these bits for initiating action.

TON timer: The output will be turned ON after a preset time once the rung becomes true. TON timer is used when the user wants to delay switching ON time of the output. The output bit turns on when preset time is equal to accumulator. Consider example of fire cracker, the lead is the delay and after you ignite the lead after some time the cracker blows off. This is an example of TON timer. For example, a blower needs to be switched ON after the operator reaches to safe place. The instruction details and timing diagram is shown in Figure 4.14.

TOFF timer: A timer that turns on immediately but turns off with a delay is called the TOFF timer. Consider an example where you need to transfer entire liquid from the vessel. In normal case, pump will be turned off after the low-level limit switch is activated, wasting liquid in the tank. Instead of this, a TOFF timer can be used and the switch off action of the pump will be delayed by a preset time. The instruction and timing diagram of the TOFF timer is as shown in Figure 4.15.

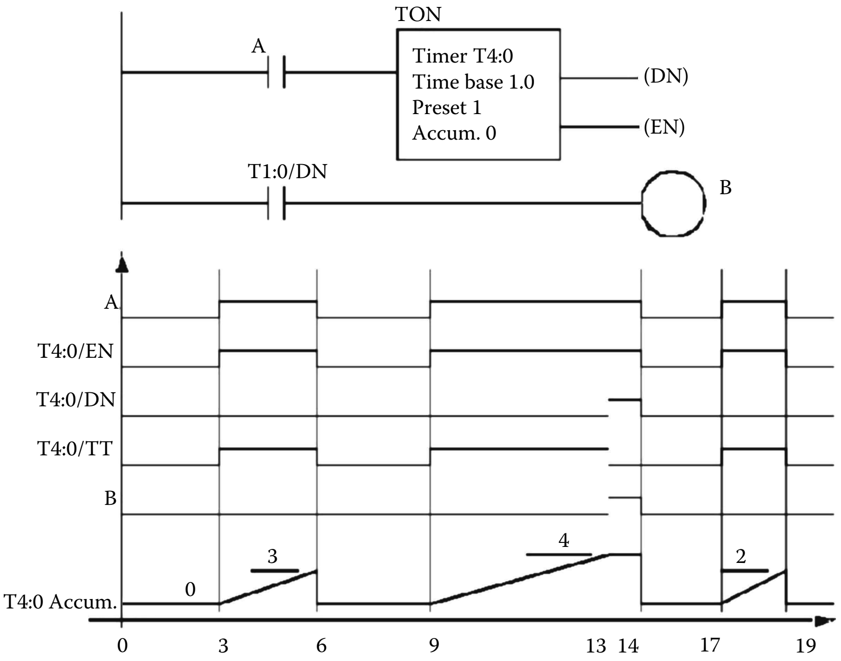

FIG. 4.14
On delay timer and timing diagram.

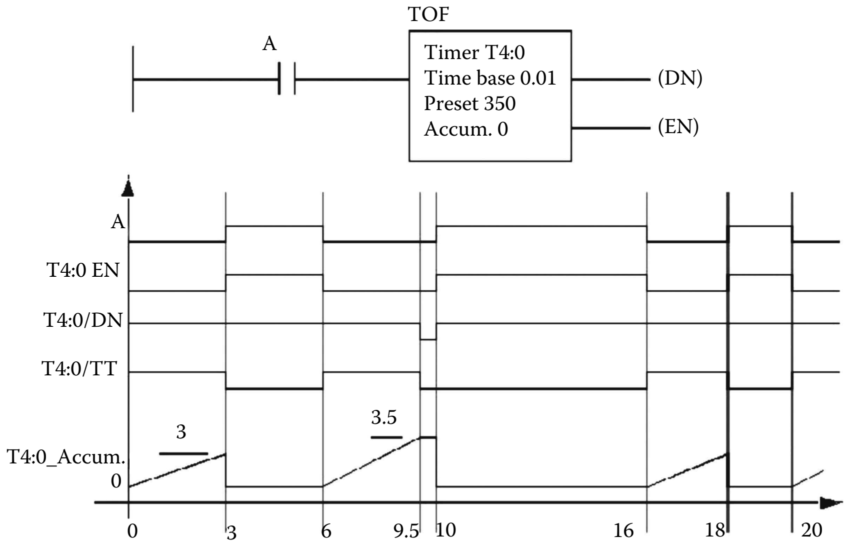

FIG. 4.15
Off delay timer instruction and timer diagram.

RTO: In case of TON and TOFF timers, the accumulator becomes zero once the rung changes from true to false. In certain applications, the timer needs to continue the counting even after the transition of the rung. This type of timer is called as RTO. The accumulator will hold the value even if the rung transits. Hence, this timer needs to be resettled. The instruction and timing diagram is as shown in Figure 4.16.

Counters

In many applications, it is required to count the number of events or objects. There are two types of counters available: up and down counters.

Up counters: In case of up counter, once the pulse is sensed, accumulator is incremented by one. Once the preset value is equal to accumulator, the counter done bit will be high. The instruction is shown in Figure 4.17.

Down counters: In case of down counter, the accumulator value is decremented after every pulse at the input of the rung. When the accumulator reaches to preset, the counter done bit is set and this bit is used for initiating other action. The instruction is as shown in Figure 4.18.

Instruction summary: Commonly used instructions are tabulated in Table 4.2.

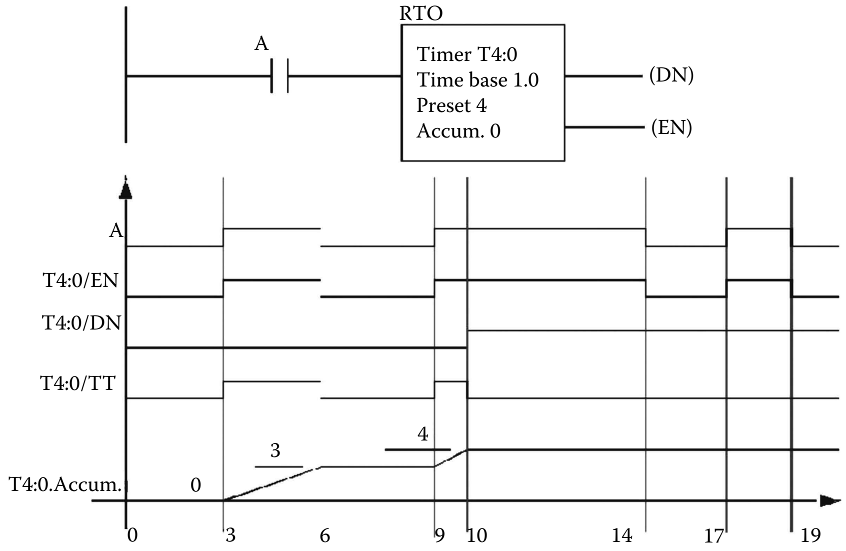

FIG. 4.16
Retentive on delay timer instruction with timing diagram.

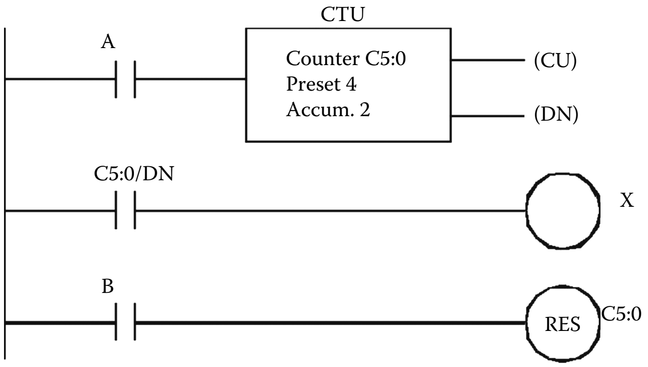

FIG. 4.17
Upcounter instruction.

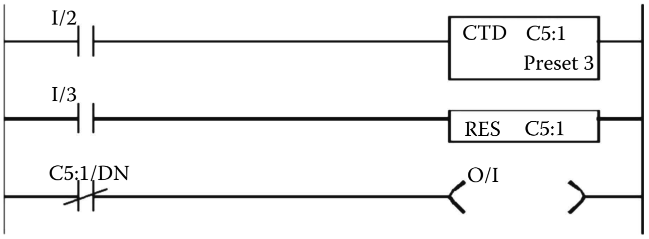

FIG. 4.18
Down counter instruction.

TABLE 4.2
Summary of PLC Instructions

Instructions		
Set	MCR	Jump
Rest	Label	Rising edge pulse
Timer: On, Off, and retentive	Counter: Up and down	Falling edge pulse
Addition	Subtraction	Multiplication
Division	Move	Compare
Logical	File	PID

Case Study

The PLC is used extensively for the automation of the plant. While carrying out the automation project, the user needs to consider certain prerequisites, which ensure the satisfaction of the plant requirements. The steps are listed as follows:

a. Thorough understanding of the process:
  - Define objectives of automation
  - Listing of input and output devices
  - Describing the process with sequence of events

b. PLC program development

With the help of a plant automation case study, the above-mentioned steps can be described. The P & I diagram of the water distribution plant is shown in Figure 4.19 for which the PLC program is to be developed.

Objective of the automation: The purpose of this plant is to supply constant flow of water to the users. The supply will be based on a fixed priority as indicated.

Input and output listing: The identified inputs and outputs are tabulated in Table 4.3.

Description of process: For the plant, the sequence of events required by the user is as mentioned below.

The steps involved in this process are listed below:

1. Water is to be maintained in the reservoir within High and Medium level (LH and LM) using water inlet valve.
2. Air pressure in the tank is to be maintained between the desired levels (e.g., 6–6.2 kg/cm^2).
3. If water level goes below medium-level, the supply of water to user 3 (low priority) will be switched off.
4. If water level goes below low in the reservoir, then the water supply of the USER-2 will be "TURNED-OFF" and at the same time a HOOTER will be "TURNED-ON." After a predefined time, the supply to user 1 will be switched off if the level remains below low.

The ladder developed for this project is as shown in Figure 4.20. The steps involved in execution of the program are as follows:

1. Write/Edit a ladder program.
2. Simulate the program using local simulator or force function.
3. Change the program if necessary.
4. Download the program to controller.
5. Run the program.
6. Change the physical inputs and verify the output status.
7. Modify the program if necessary based on the different field conditions.

RECENT TRENDS IN PLCs

The advancements in communication and electronics have paved way for major strategic changes in the architecture of PLC. The remote I/O configuration has drastically reduced the execution time and further strengthened the distributed architecture. The information collected at device level formed the sensor network. Open networks are playing important role in the progress of PLCs. DeviceNet is an example of the most widely used open network. This network can directly be connected to sensors or field instruments. The diagnosis is available at network level due to two-way communication with the

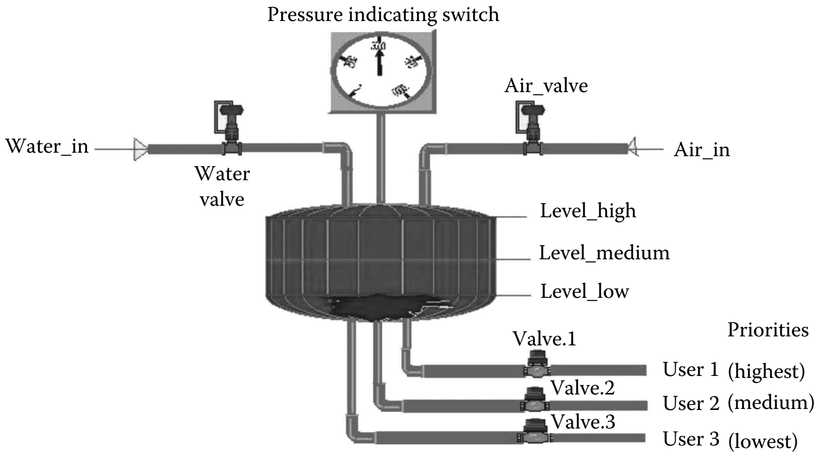

FIG. 4.19
P&I diagram for water distribution plant.

TABLE 4.3
List of I/Os for the P & I Diagram

Input	*Output*
Water level switches	On-Off valves
High [LH]	Water valve
Medium [LM]	Air valve
Low [LL]	Solenoid valve for User 1
	Solenoid valve for User 2
	Solenoid valve for User 3
Pressure switches	
Pressure high [PSH]	
Pressure low [PSL]	

help of main controller. Similarly, controlnet is another complementary network to deviceNet. This network is complex and ensures the delivery of message at odd times faithfully. Ethernet is also being used by many to transmit the data at higher rates. The integrated architecture is now becoming a popular control philosophy wherein broad ranges of applications are covered. In such a philosophy, duplication of data and tags are avoided. For all the stake holders, the view mode remains same; hence, the uniformity in understanding of the plant-wide concepts becomes easy. The data is moved throughout the network seamlessly, hence multiple physical networks are viewed as single network by the user. As this is supporting open networks, it reduces time for integration

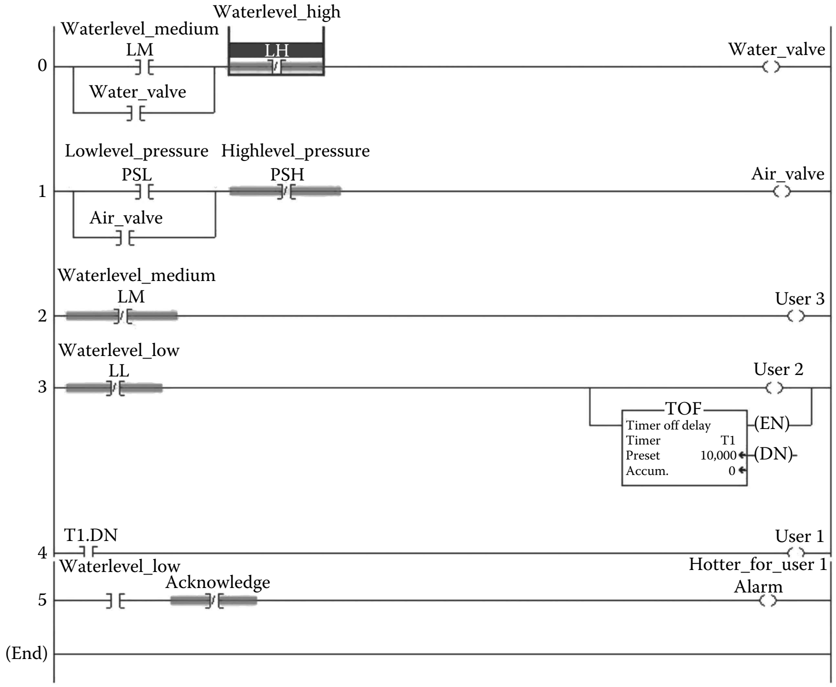

FIG. 4.20
Ladder diagram for water distribution plant.

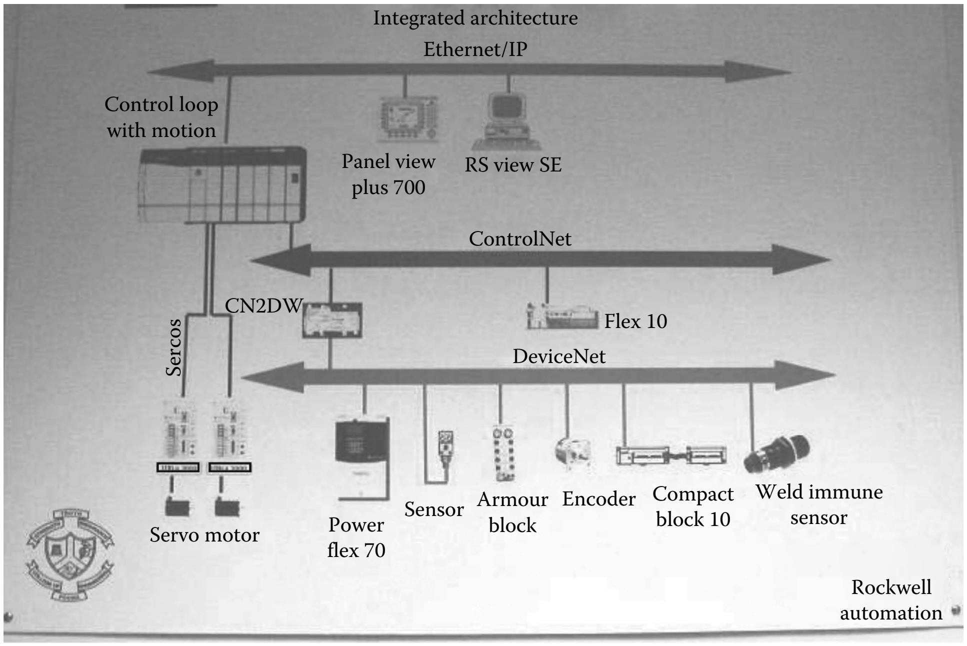

FIG. 4.21
Typical integrated architecture.

and cost for commissioning. The cross referencing of the tags and physical addresses is not required. Highest layer of data exchange through manufacturing enterprise system is possible due to this type of structure. All disciplines of control can be targeted like batch, continuous, motion, drive, enterprise, and discrete. As a case study, Figure 4.21 indicates the integrated architecture implemented by Rockwell Automation in an educational institute for demonstration of state-of-art technology.

Abbreviations

PLC	Programmable logic controller
CPU	Central processing unit
RTD	Resistance temperature detector
D/A	Digital to analog converter

Bibliography

Bradley, A. Logix 5000 Controller Information and Status, Programming Manual Rockwell Automation, July 2008.

Dunning, G. *Introduction to Programmable Logic Controllers*, 3rd edn., Delmer Thomson Learning, 2006.

Jack, H. *Automating Manufacturing System with PLC's,* ebook version 2.3, April 2003.

Morriss, S.B. *Programmable Logic Controllers*, Prentice Hall, 1999.

Web, J.W. and Reis, R.A. *Programmable Logic Controller: Principles and Applications*. Englewood Cliffs, NJ: Prentice-Hall Publication, 1995.